

## BRIEF DESCRIPTION OF THE DRAWINGS

[0038] These and/or other exemplary aspects and advantages will become apparent and more readily appreciated from the following description of the exemplary embodiments, taken in conjunction with the accompanying drawings in which:

[0039] FIG. 1 is a perspective view illustrating a graphene device according to an exemplary embodiment;

[0040] FIG. 2 is a cross-sectional view taken along X-X of FIG. 1;

[0041] FIG. 3 is a cross-sectional view taken along Y-Y of FIG. 1;

[0042] FIG. 4 is an enlarged view illustrating a meta atom illustrated in FIG. 1;

[0043] FIG. 5A is a conceptual view illustrating a carbon atom arrangement of graphene;

[0044] FIG. 5B is a diagram illustrating an energy band structure in the vicinity of a Fermi level of graphene;

[0045] FIG. 6 is a diagram illustrating an energy change of graphene depending on a gate voltage according to an exemplary embodiment;

[0046] FIG. 7 is a view for explaining a graphene device that operates as a filter according to an exemplary embodiment;

[0047] FIG. 8 is a diagram illustrating an example in which electrons and holes are in an unbalanced state at an interface between a graphene layer and a meta atom;

[0048] FIG. 9A is a graph illustrating a wavelength band of light incident to a graphene device according to an exemplary embodiment;

[0049] FIG. 9B is a graph illustrating a wavelength band of light reflected by a graphene device according to an exemplary embodiment;

[0050] FIG. 10 is a graph illustrating a Q-factor of a graphene device according to an exemplary embodiment;

[0051] FIG. 11 is a view illustrating a graphene device that may modulate light by using control light according to an exemplary embodiment;

[0052] FIGS. 12A and 12B are views for explaining waves reflected by a graphene device depending on a gate voltage according to an exemplary embodiment;

[0053] FIGS. 13 to 16B are views for explaining a method of manufacturing a graphene device according to an exemplary embodiment;

[0054] FIG. 17 is a view illustrating a graphene device according to an exemplary embodiment; and

[0055] FIGS. 18 to 20 are views illustrating an example of a meta atom applicable to a graphene device according to an exemplary embodiment.

## DETAILED DESCRIPTION

[0056] As the terms used herein, so far as possible, widely-used general terms are selected in consideration of functions in the inventive concept; however, these terms may vary according to the intentions of those of ordinary skill in the art, the precedents, or the appearance of new technology. Also, in some cases, there may be terms that are arbitrarily selected by the Applicant, and the meanings thereof will be described in detail in the corresponding portions of the description of the inventive concept. Therefore, the terms used herein are not simple titles of terms and should be defined based on the meanings thereof and the overall description of the inventive concept.

[0057] The terms “configure” and/or “comprise” used herein should not be construed as necessarily including all components or operations described in the specification, but should be construed as not including some components or operations or further including additional components or operations.

[0058] Hereinafter, embodiments provided for exemplary purpose only are described below with reference to the accompanying drawings. Exemplary embodiments below are provided for only implementation of the inventive concept and should not be construed as limiting the scope of the inventive concept, and things that are easily inferred from the detailed description and exemplary embodiments by a person of ordinary skill in the art should be construed as belonging to the scope of exemplary embodiments.

[0059] FIG. 1 is a perspective view illustrating a graphene device 100 according to an exemplary embodiment, FIG. 2 is a cross-sectional view taken along X-X of FIG. 1, FIG. 3 is a cross-sectional view taken along Y-Y of FIG. 1, and FIG. 4 is an enlarged view illustrating a meta atom 20 illustrated in FIG. 1.

[0060] As illustrated in FIGS. 1 to 4, the graphene device 100 may include a substrate 10, a plurality of meta atoms 20 spaced apart from each other and having a radial shape, a graphene layer 30 disposed on the substrate 10 and covering the plurality of meta atoms 20, and a dielectric layer 50 disposed on the graphene layer 30. The dielectric layer may cover all or a portion of the graphene layer.

[0061] The substrate 10 may include an insulating material having a large band gap. The insulating material may be selected depending on a function to be performed by the graphene device 100. For example, in a case in which the graphene device 100 is to operate as a filter or a switching device, the substrate 10 may include a plastic material. In this case, the plastic material forming the substrate 10 may be one or more organic materials.

[0062] Also, in the case in which the graphene device 100 is to operate as an optical modulator that modulates light and is controlled according to control light incident thereon, the substrate 10 may include a material having a band gap larger than the energy of the control light. When the band gap of the substrate 10 is larger than the energy of the control light, a reaction between the substrate 10 and the control light does not occur. The substrate 10 may be a sapphire substrate having a large energy band gap.

[0063] The plurality of meta atoms 20 may be spaced apart from each other on the substrate 10. The plurality of meta atoms 20 may be arranged in a lattice configuration. FIG. 1 illustrates the plurality of meta atoms 20 are arranged in a two dimensional lattice configuration. The plurality of meta atoms 20 are not limited thereto and may be arranged in one dimension. The plurality of meta atoms 20 may be referred to, collectively, as a meta material.

[0064] Each meta atom 20 may be a material patterned and structured into a predetermined size. Each meta atom 20 may have a size less than a wavelength of light in a visible light band, and may have an arbitrary refractive index not existing in the natural world with respect to an electromagnetic wave or a sound wave. The meta atoms 20, included in the graphene device 100 according to an exemplary embodiment, may reflect specific light from among light incident thereon.

[0065] Each meta atom 20 may have a radial shape with branches extending outward from a specific point. FIG. 4